International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

An Approach to a Preliminary Groundwater Quality Analysis of Southern Ontario

Mezmure Haile-Meskale Ph.D. PGeo*

HydroGeoSciences Group (HGSG), 207–19 Four Winds Drive, Toronto, M3J 2S9, Canada
Email: mhaileme@gmail.com

Abstract

This study describes an approach that is found to be very useful for an initial and preliminary interpretation of analytical database. In particular, this study suggests a systematic use of an Excel Macro Program and subsequent mapping in GIS.

From the meaningful concentration ranges and the corresponding colour codes assigned in mapping, the results of the study show the methodology employed makes initial interpretation very simple, providing a partial synoptic view of groundwater quality that is easy to decipher.

Keywords: Concentration ranges; Standard; Excel Macro Program and GIS Mapping; Health-related Parameters; Environmental Constraints.

---

* Corresponding author.

1. Introduction

Based on a notion that a more meaningful result can be attained, if the concentration ranges indicated on the GIS maps are not arbitrary, or just based on simple geostatistical breaks, but are reasonably divided according to concentration ranges that depict environmental and/or health-related conditions, this study attempts to show how the concentrations of the following chemicals considered to be present in natural waters [1, 2] have been used for a preliminary interpretation of groundwater quality in Southern Ontario: total dissolved solids (TDS), conductivity, hardness, alkalinity, pH, total kjeldahl nitrogen (TKN), ammonia (NH_3), nitrate (NO_3), nitrite (NO_2), dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), ortho-phosphate (PO_4), total phosphorus (TP), sulphate (SO_4), chloride (Cl), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), fluoride (F_2), silica (Si), mercury (Hg), bromide (Br), iron (Fe), manganese (Mn), aluminium (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), boron (B), cadmium (Ca), chromium (Cr), Mercury (Hg), Cyanide (Cn), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), molybdenum (Mo), nickel (Ni), selenium (Se), silver (Ag), strontium (Sr), thallium (Tl), titanium (Ti), uranium (U), vanadium (V), and zinc (Zn).

An analytical database consisting of over 5000 data points mostly from monitoring wells and piezometers that have been collected during various seasons, over many years (1947 to 2015) from Southern Ontario was assessed (**Figure 1**).

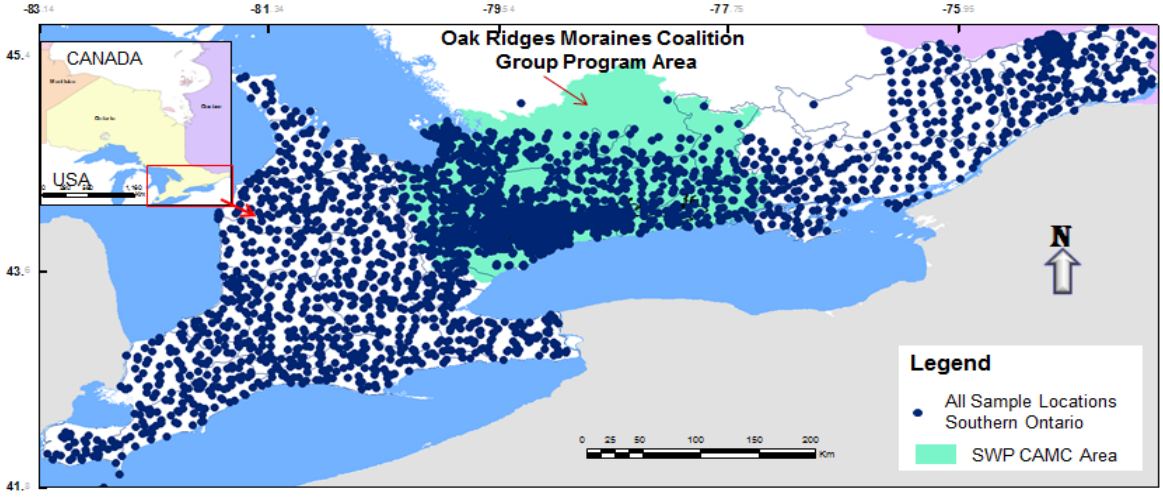

Figure 1: Location of the study area

The greenish shaded area in Figure 1 shows the sample points from which the database of more than half of the total have been managed by the Oak Ridges Moraines Coalition Group. Average values of about 3600 of these sample points within 10% error were used in the following discussion.

Primarily, this study integrates analytical data with any other relevant number (s) to compare with, such as Standard, natural and/or local background and method detection limits. Subsequently, the concentrations of each chemical parameter are compared with concentration ranges that provide meaning with respect to public health and environmental conditions. Such information is tied with other well and aquifer information, followed

by GIS mapping. The concentration ranges provided in this study are based on a review of several textbooks. For example, the relative hardness of groundwater [1, 2] can be divided into ranges that indicate if the water is relatively very soft (equal to or less than 80 mg/L), soft (between 80 and 100 mg/L), medium (between 100 and 150 mg/L) hard to very hard (between 150 to 500 mg/L) and extremely hard (equal to above 500 mg/L).

Having categorized the parameters in accordance with their level of significances, the concentration ranges of few of the most significant parameters are mapped, thus providing a synoptic view of groundwater quality of Southern Ontario. It should be noted, however, that the chemical outliers presented in this study may not have any direct effect on public health since almost all the samples analyzed were collected from monitoring wells, not used for drinking purposes.

2. Methodology

The methodology employed in this study can be divided as in the following:

- First, all the parameters enlisted in section 1.0 are tentatively regrouped based on their known overall importance to water chemistry.
- A statistical relationships was determined through correlation matrices, from which the significance of individual or groups of chemical parameters is assessed.
- Parameter concentrations were compared with available detection limits, existing Standards and background values (natural and environmental).
- The parameter concentrations were again compared with the concentration ranges for which data is available from textbooks providing information on health and environmental conditions.
- By running an in-house Excel Macro Program, the overall database was mapped forming a colour coded conditionally formatted table. This table is then thought to provide a synoptic view of the overall groundwater quality situations in Southern Ontario.
- For the minor constituents and trace metals, the relative significance of the respective concentrations was determined by counting the number of samples that exceeded the calculated average method detection limit (MDL).
- The relative significance of the parameters themselves in the groundwater quality of Southern Ontario was then assessed by counting the number of samples that exceeded the detection limits and calculating the respective percentages from the total samples.
- In using all the above information, two parameters from each of the six significant parameters, enlisted in section 3.1 were selected, and the corresponding relevant concentration ranges mapped on GIS, thus portraying a synoptic view of the spatial groundwater quality with respect to only the selected parameters.

3. Discussion

*3.1 The interrelationship between chemicals and regrouping of che*micals

The inter-relation between parameters (correlation matrix) was calculated from the average values of the chemical parameters (**Table 1**).

Table 1: Correlation of TDS, hardness and pH with major ions and some minor sonstituents

Parameters	*TDS*	*Hardness*	*pH*	*Calcium*	*Magnesium*	*Sodium*	*Potassium*	*Sulphate*	*Chloride*	*Strontium*	*Barium*	*Boron*	*Iron*	*Manganese*	*Aluminum*	*Zinc*	*Fluoride*	*Nitrate*
TDS	1.000																	
Hardness	0.692	1.000																
pH	-0.140	-0.258	1.000															
Calcium	0.591	0.850	-0.245	1.000														
Magnesium	0.629	0.804	-0.145	0.522	1.000													
Sodium	0.745	0.328	0.015	0.271	0.361	1.000												
Potassium	0.454	0.257	-0.103	0.192	0.263	0.500	1.000											
Sulphate	0.516	0.853	-0.103	0.729	0.666	0.192	0.158	1.000										
Chloride	0.750	0.357	-0.062	0.276	0.372	0.924	0.494	0.121	1.000									
Strontium	0.254	0.282	-0.028	0.263	0.240	0.126	0.071	0.293	0.128	1.000								
Barium	-0.006	-0.013	0.029	-0.012	-0.006	0.007	0.006	-0.016	0.008	0.009	1.000							
Boron	0.427	0.249	0.113	0.187	0.226	0.465	0.336	0.297	0.388	0.087	0.036	1.000						
Iron	-0.003	0.016	0.023	0.020	0.007	-0.022	0.006	0.002	-0.008	0.096	0.002	0.027	1.000					
Manganese	0.034	0.025	-0.010	0.037	0.019	0.029	0.031	0.018	0.030	0.024	0.002	0.055	0.181	1.000				
Aluminum	-0.012	-0.014	0.030	-0.012	-0.007	-0.007	-0.005	-0.007	-0.006	0.291	0.187	0.000	0.100	0.019	1.000			
Zinc	0.011	0.043	0.019	0.028	0.060	-0.014	-0.019	0.051	-0.013	0.107	0.047	-0.029	0.009	0.018	0.039	1.000		
Fluoride	-0.009	-0.003	0.006	-0.003	0.000	-0.005	0.007	-0.003	-0.004	0.325	-0.010	0.307	-0.002	-0.015	-0.018	0.027	1.000	
Nitrate	0.079	0.133	0.028	0.110	0.117	0.006	0.013	0.162	-0.011	-0.111	-0.015	-0.106	0.000	0.025	-0.010	0.027	-0.001	1.000

Legend	
>=0.75	Very high
between 0.75 and 0.5	High
between 0.5 and 0	no correlation
Less than 0	negative correlation

The chemical parameters that are closely related to one another can be identified from this table. Consequently, those groups of chemicals that are responsible for the natural and/or anthropogenic impact can be speculated from this table.

The correlation matrix in Table 1 shows three parts indicating the interrelations among three parameter groups - general chemistry, major ions and some of the minor constituents. In this table, those with very high correlation (>=0.75) are indicated in red; those with medium correlations (between 0.5 and 0.75) in yellow, those with no correlation (between 0 and 0.5) in purple; and those that may be negatively correlated or no correlation in light green. As seen from the Table, TDS, hardness, and pH are more correlated with the major ions than with the minor constituents. For example, there exists a very high correlation (0.75) between TDS and chloride; high correlation (0.692) between TDS and hardness; no correlation (0.427) between TDS and boron; and negative (-0,009) or no correlation between TDS and fluoride.

It can be seen from the middle part of Table 1 that the major ions are more interrelated within themselves than with the minor constituents. Also, it can be observed from the right side of Table 1, that the minor constituents do not exhibit any correlation within themselves.

Hence, based on Table 1, and a priori knowledge of previous investigations in the Southern Ontario [3], the chemical parameters enlisted in section 1.0, have been regrouped in a meaningful way. More analysis in the subsequent sections of this particular study has also helped in regrouping the chemical parameters into the following six groups:

1) General Groundwater quality Indicators:

- total dissolved solids (TDS), conductivity, hardness, pH, dissolved inorganic carbon (DIC) and Langelier Index (LI)

2) Major ions (Dominant ions – or solutes):

- Cations (positive ions):- sodium (Na^+), potassium (K^+), calcium, (Ca^{2+}), magnesium (Mg^{2+})
- Anions Cations (negative ions):- chloride (Cl^-), sulphate (SO_4^{2-}), bicarbonate + carbonate (HCO_3^- & CO_3^{2-})[a]

3) Minor constituents (less dominant ions – or solutes):

- commonly known as health related:
  - nitrate (NO_3^-) and nitrite (NO_2), fluoride (F^-);
- commonly known as contamination indicators:
  - ammonia (NH_3^-), total kjeldahl nitrogen (TKN), dissolved organic carbon (DOC),

ortho-phosphate (PO_4) and total phosphorus (TP).

4) Minor constituents and metals with relatively significant concentration[b]:

- iron (Fe), manganese (Mn), strontium (Sr), boron (B), barium (Ba), reactive silicates (Si), aluminium (Al) and zinc (Zn)

5) Trace metals (< 1 mg/L), having drinking water Standard:

- those that are commonly known as health related:
  - mercury (Hg), antimony (Sb), arsenic (As), chromium (Cr), lead (Pb), selenium (Se), and uranium (U);
- and those that are commonly known as non-health related:
  - Cadmium (Cd), copper (Cu) and vanadium (V)

6) Trace Metals (< 1 mg/L) not having drinking water Standard[c]:

- Beryllium (Be), cobalt (Co), molybdenum (Mo), nickel (Ni), silver (Ag), thallium (Tl), titanium (Ti).

This study has followed the order and set up of the analytical database as enlisted above; both well and aquifer

[a] Bicarbonates have been deduced from alkalinity.

[b] From a priori knowledge, based on previous investigations in the Southern Ontario [3], the concentrations of these minor constituents is found to be relatively significant (see also section 3.2.4).

[c] These are commonly known as non-health related (in this study, other standards, such as standards set for domestic, irrigation and aquatic life purposes has been used).

parameters are linked to the analytical database.

3.2 Comparing the whole analytical database with concentration ranges

The average concentrations of all the parameters were compared with existing Standards and concentration ranges that depict some environmental conditions. The subsequent number of counts from the total number of samples analyzed (also the corresponding percentages) is thought to provide, accordingly, the significance of the individual parameter concentrations in Southern Ontario, from which groundwater quality can be speculated on a regional scale. These are presented on separate tables for each of the groups in section 3.1

3.2.1 General groundwater quality indicating parameters

The concentrations of each parameter is compared with known Standards and other concentration ranges from which the number of counts and percentages has been calculated. (**Table 2**).

Table 2: Number of counts and percentages of the general groundwater parameters compared to known Standards and other certain concentration ranges

Parameters	TDS					Cond	DIC	Langelier Index			Hardness					pH		
Total analyzed	3689					4066	3365	3177			1121					3413		
Standard and range	<500	500-1000	1000-3000	3000-10000	>=10,000	769	50.00	,=-1	0.00	>=1	<80	80-100	100-150	150-500	>500	<=6.5	6.5-8.5	>=8.5
No.of samples	2140	1108	390	47	4	1324	2012	128	2913	136	41	18	94	882	86	130	3211	72
Percentages	58.0	30.0	10.6	1.3	0.1	32.6	59.8	4.0	91.7	4.3	3.7	1.6	8.4	78.7	7.7	3.8	94.1	2.1

It is assumed that by comparing the very wide range of TDS values from the database, with the range of values indicated in Table 2, the order of magnitude of the groundwater quality variations in Southern Ontario, as reflected by just TDS can be deciphered. For example, water is considered tolerable for drinking purposes, if total dissolved solids (TDS) has any value between 500 and 1000 mg/L; it is considered as undesirable or slightly saline, if TDS is between 1000 and 3000 mg/L; it is considered as moderately saline if TDS is between 3000 and10, 000 mg/L and saline if TDS is greater than10, 000 mg/L.. [1, 2].

It can be seen from the Table that out of the 4597 samples analyzed for TDS, most of the groundwater is fresh (61% is less than the Standard); some of the groundwater (28%), although above the Standard, is tolerable for drinking purposes. Few samples (9.7%) are found to be slightly saline; very few samples (1.3%) are found to be moderately saline, and very few (0.1%) samples are found to be saline [1, 2].

Also, it can be seen from Table 1 that out of the 3526 samples analyzed for Langelier index most of the groundwater is neither under saturated nor over saturated [4]. Similarly, the pH range indicates that most waters are neither acidic nor alkaline (94% being close to 7). However, the same table indicates that most groundwater (78%) is hard.

3.2.2 Major ions (dominant ions or solutes)

The concentration of each major ions (dominant ions – or solutes), is compared with known Standards and other concentration ranges, from which the number of counts and percentages has been calculated (**Table 3**).

Table 3: Number of counts and percentages of the major ions compared to known Standards and other concentration ranges

Parameters	Alk	Ca	Mg	Na			K	SO4	Cl
Total analyzed	3681	3695	3689	3674			3479	3693	3680
Standard and range	>=500	>=50	>=30	<=20	20-200	>=200	>=10	>=500	>=250
No.of samples	10	120	86	1806	1599	269	227	206	297
Percentages	0.3	3.2	2.3	49.2	43.5	7.3	6.5	5.6	8.1

The major ions, although not considered as general groundwater quality indicators, the concentrations of some, such as sodium and chloride, could be of interest for various reasons. For example, sodium exceeding 20 mg/L may be an issue for people with hypertension, and high concentrations of chloride (above 250 mg/L) could indicate the presence of either natural groundwater deterioration or artificial contamination. As indicated in Table 3, few groundwater samples (8.3%) have an undesirable level (above 200 mg/L of sodium. This may correspond to the 7.5% chloride, which is on the high range [5].

3.2.3 Minor constituents (less dominant ions or solutes)

The concentrations of each minor constituents (less dominant ions or solutes), commonly known as health-related, and other minor constituents that are commonly known as contamination indicators are compared with known Standards and other concentration ranges, from which the number of counts and percentages have been calculated (**Table 4**). As indicated in Table 3, nitrate levels are minimal (<= 3 mg/L) in most samples (over 80%). Since the natural occurrence level of nitrate is very low (close to 1 mg/L), few samples (6.8%) that have nitrate levels between 3 and 5 mg/L might probably indicate a possibility of nitrate contamination. There could be even a higher chance of contamination in few of the samples (6%) that have nitrate concentration between 5 and 10 mg/L.

Table 4: Number of counts and percentages of the minor constituents (health-related and contamination indicators) compared to known Standards and other concentration ranges

Parameters	NO3					NO2	NH3	PO4	TP	DOC	F		
Total analyzed	3472					3328	3348	3294	700	3186	3310		
Standard and range	<=3	3-5	5-10	10-20	>=20	>=1	>=.5	>=1	>=1	>=5	<=1.5	1.5-2.4	>=2.4
No.of samples	3042	193	162	62	13	8	481	54	50	277	3003	261	46
Percentages	87.6	5.6	4.7	1.8	0.4	0.2	14.4	1.6	7.1	8.7	90.7	7.9	1.4

Some studies [7, 8, and 9] indicate nitrate concentrations greater than 20 mg/L to be above the Lowest Observable Adverse Effect Level (LOAEL). It can be seen from Table 4 that 80 out of 4531 wells (1.8%) exceed 20 mg/L. Table 4 also shows various levels of fluoride. As indicated in Table 3, fluoride levels are minimal (<= 1.5 mg/L) in most samples (over 87%).

In recognition of the fact that values slightly exceeding 1.5 mg/L of fluoride level may not be considered health hazard [6]. ".. Where supplies contain naturally occurring fluoride at levels higher than 1.5 mg/L, but less than 2.4 mg/L, the Ministry of Health and Long-Term Care recommends an approach through local boards of health to raise public and professional awareness to control excessive exposure to fluoride from other sources." It can be seen from Table 4 that 369 wells (9.3%) have fluoride levels between 1.5 mg/L and 2.4 mg/L and may be of concern but not necessarily a health hazard. However, 128 out of 4531 wells (3.2%) have exceeded the 2.4 mg/L, thus suggesting the need for special attention.

All the rest of the parameters in Table 4 (nitrite, ammonia, orthophosphate, dissolved organic carbon and total phosphorus) show slight exceedances above the DWS, thus indicating, most probably, the presence contamination in few wells.

Ammonia is not considered as a health-related parameter. However, high ammonia values may indicate contamination, as ammonia could be converted to nitrate under a higher oxidizing condition. Similarly, dissolved organic carbon (DOC) exceeding 5 mg/L is not considered desirable in drinking water; its exceedance above the 5 mg/L is indicative of the presence of organic contamination.

It is interesting to note that some or all of the 342 (9.1%) wells exceeding 5 mg/L of DOC are congruent to some of the 471 wells (10.4%) exceeding the 5 mg/L of nitrate indicated in Table 4, thus confirming the possibility of environmental degradations going on in few places.

3.2.4 Minor constituents and metals with relatively significant concentration

The concentrations of minor constituents and metals with previously known relatively significant concentration [4] are compared with the Standards, from which the number of counts and percentages have been calculated (**Table 5**).

Table 5: Number of counts and percentages of some minor constituents including some metals compared to MDL

Parameters	Iron		Manganese		Strontium		Barium		Boron		SiO2		Aluminum		Zinc	
Total analyzed	3668		3477		3198		3255		3225		3349		3434		3279	
Standard and range	>=0.3		>=0.05		>=40		>=1		>=5		>=30		>=0.1		>=5	
Number of samples	1423	2446	639	3073	13	3166	27	3211	12	2317	7	3348	59	1565	1	2115
Level of Significance	HS	HS	HS	HS	LS	HS	LS	HS	LS	HS	LS	HS	MS	MS	LS	HS
Percentages	38.79	66.68	18.38	88.38	0.41	99.00	0.83	98.65	0.37	71.84	0.21	66.89	1.72	45.57	0.03	64.50

In this study, the average detection limit (MDL) was calculated and compared with the average concentrations of the minor constituents including some metals. Apart from comparing with available Standard, the reason for comparing MDL is to examine the relevance of each parameter in the groundwater samples, as MDL is a very useful means of knowing or reassuring that a certain substance, in particular, trace elements, exists in the water sample. It is possible that trace amounts of certain substances that actually exist in a water sample may not have been detected (reported), or that some trace metals may be totally absent from the sample. In any case, it is thought the significance of trace metals can be assessed by counting the number of wells from which any particular parameter is detected.

In Table 5, the number of samples (in black) shows exceedances above the Standard, and the respective percentage was calculated by dividing these numbers by the total number of samples analyzed. This table also shows the numbers of samples (in bluish colour) showing exceedances above the method detection limit (MDL). Again, the respective percentage was calculated by dividing these numbers by the total number of samples analyzed. The relative level of significances of each parameter within Table 5 is arbitrarily provided below:

For the exceedances above the Standard, the following arbitrary level of significance (in black) was assigned: LS = relatively less significant (less than 1% of the total sample detected); MS= medium significant (between 1% and 5% of the total sample detected); HS= highly significant (greater than 5% of the total sample detected).

For the exceedances above MDL, the following arbitrary level of significance (in bluish colour) was assigned: LS = relatively less significant (less than 10% of the total sample detected); MS= medium significant (between 10% and 50% of the total sample detected); HS= highly significant (greater than 50% of the total sample detected).

Amongst all the parameters in table 5, those that can be considered most significance are highlighted in reddish colour, whereas those that are of medium significance are highlighted in yellow. As shown in the black coloured numbers in the first two columns of Table 5, only iron and manganese have relatively higher exceedances (HS in the table) above the Standard (39% and 18%, respectively). All the rest have low levels of exceedances (LS), with the exception of aluminum that has a medium level of significance (MS). Obviously, all the parameters in table 6 are significant (HS) with respect to MDL. Although the results from the above exercise may indirectly describe the order of magnitude of groundwater quality variations, better assessment of the environmental conditions can be attained from the spatial distribution of these wells (**Section 5.0**).

3.2.5 Trace metals (< 1 mg/L) having drinking water Standard

The concentration of each trace metals (< 1 mg/L) having drinking water Standard is compared with the Standards and method detection limit (MDL), from which the number of counts and percentages has been calculated (**Table 6**).

Table 6 shows the number of counts and percentages when data of trace metals (< 1 mg/L), having drinking water Standard is compared with known Standards and Method Detection Limits (MDL). When the magnitude of both the Standard and MDL exceedances is counted, it may seem that the parameters in table 6 are not as

important as those in table 5. However, each parameter may have its unique significance in groundwater beyond what this study can decipher. It would, therefore, be prudent to view table 6 by the same measure of the relative level of significances. Hence, as shown in the black coloured numbers of Table 6, the exceedances above the Standard are not alarming (no HS). However, antimony, cadmium and selenium are found to be of medium significance (MS) with respect to exceedances above the Standard.

Contrary to table 5, none of the parameters in table 6 is relatively highly significant (HS) with respect to MDL. However, the overall table indicates that all have some level of significance, thus reassuring their presence although in a very limited amount.

Table 6: Number of counts and percentages of trace metals (< 1 mg/L) having drinking water compared to known Standards and MDL

Parameters	Mercury		Antimony		Arsenic		Cadmium		Chromium		Copper		Lead		Selenium		Uranium	
Total analyzed	2737		3163		3222		3217		3244		3274		3254		3217		3148	
Standard and range	>=0.001		>=0.006		>=0.025		>=0.005		>=0.05		>=1		>=0.01		>=0.01		>=0.02	
Number of samples	19	54	46	430	12	834	42	98	4	64	1	573	25	306	115	1175	15	1174
Level of Significance	LS	LS	MS	MS	LS	MS	MS	LS	LS	LS	LS	MS	LS	LS	MS	MS	LS	MS
Percentages	0.69	1.97	1.45	13.59	0.37	25.88	1.31	3.05	0.12	1.97	0.03	17.50	0.77	9.40	3.57	36.52	0.48	37.29

3.2.6 Trace Metals (< 1 mg/L) without drinking water Standard

The concentration of each trace metals (< 1 mg/L), without drinking water Standard is compared with Standards other than drinking, such as domestic, irrigation, aquatic life, and with method detection limit (MDL), from which the number of counts and percentages has been calculated (**Table 7**).

Table 7: Number of counts and percentages of some trace metals (< 1 mg/L) without drinking water standard compared with other standards set for other purposes and with MDL

Parameters	Vanadium		Nickel		Silver		Cobalt		Beryllium		Molybdenum		Thallium		Titanium	
Total analyzed	3112		3199		3142		3226		681		3192		3093		3131	
Standard and range	>=0.1		>=0.2		>=0.005		>=0.05		>=0.1		>=0.01		>=0.1		>=0.1	
Number of samples	1	489	2	449	45	77	11	194	0	130	283	2115	2	86	3	151
Level of Significance	LS	MS	LS	MS	MS	LS	LS	LS	LS	MS	HS	HS	LS	LS	LS	LS
Percentages	0.03	15.71	0.06	14.04	1.43	2.45	0.34	6.01	0.00	19.09	8.87	66.26	0.06	2.78	0.10	4.82

The percentages in table 7 have also been classified by the same measure of the relative level of significances as in Tables 5 and 6. As shown in the black coloured numbers of Table 7, silver is found to be of medium

significance (MS) with respect to exceedances above the Standard. The exceedances above the Standard of molybdenum is considered high (above 5%). From the percentage of its exceedance above the MDL, its presence in the groundwaters of Southern Ontario can be considered highly significant.

4. An example from a conditionally formatted database

A synoptic view of groundwater quality Southern Ontario has been possible by comparing parameter concentrations with the natural background values and the Standard. Natural background values are those values that are typical of the respective parameters considered across the globe. Natural background values provided in textbooks and water quality sourcebooks [1, 2], and Standards are provided in Guidelines [6, 8, 9]. Although these natural background values may be known, the local background values could vary from place to place, depending on site-specific natural (mainly geological) characteristics, as well as site-specific artificial contaminations. For example, if the area of interest is a volcanic region with significant hydrothermal activities, fluoride concentrations could be significantly high such that the background fluoride for that area could be much more than what is normally considered above the Standard elsewhere. In this study, the on-site (local) background values were calculated from existing data population, using an Excel Macro Program [11]. However, when the results were compared with the natural background values from textbooks, no significant difference was found between the two, which indicates the absence of the exceptional geologic condition or anthropogenic impact from where the samples were collected. Hence, the concentration ranges of all the chemical parameters analyzed, as well as the natural (not local background) background values have been used for comparison. Accordingly, the whole database was conditionally formatted using an in-house developed Excel Macro Program [12]. The program quickly displays the occurrences of parameter concentrations within the defined concentration ranges in different colours (**Table 8**).

Table 8: Concentration ranges from a small part of the conditionally formatted database

Parameter	TDS	Hardness	Na	Cl	NO3	F	Fe	Mn	Al	Sb	Cd	Se	Ag	Mo
Background	250	80	10	125	3.00	0.50	0.10	0.03	0.100	0.004000	0.002500	0.001000	0.000020	0.009000
Standard	500	100	20	250	10.00	1.50	0.30	0.05	1.000	0.006000	0.005000	0.010000	0.005000	0.010000
1	385	200	33	3	0.03	0.29	0.04	0.03	0.070	0.011500	0.000100	0.002000	0.000150	0.010000
2	265	215	7	11	1.79	0.05	0.11	0.02	0.069	0.000435	0.000014	0.000650	0.000012	0.000328
3	141	76	23	2	1.16	0.29	0.10	0.01	0.001	0.000424	0.000009	0.000510	0.000011	0.002753
4	282	183	36	27	0.04	0.35	0.35	0.02	0.218	0.007400	0.004050	0.600800	0.000100	0.017200
5	294	232	8	18	1.15	0.05	7.82	0.09	0.006	0.000482	0.000536	0.000439	0.000029	0.000163
6	297	241	8	17	3.61	0.09	0.57	0.02	0.058	0.113134	0.000788	0.001467	0.011678	0.003644
7	269	232	3	3	1.23	0.08	0.05	0.01	0.073	0.100462	0.000521	0.000910	0.010513	0.003274
8	356	85	97	87	0.14	1.39	0.78	0.02	0.005	0.000554	0.000160	0.000650	0.000001	0.056360
9	721	326	152	280	0.16	0.50	0.71	0.05	0.016	0.000937	0.000097	0.014386	0.000014	0.000439
10	303	253	4	4	0.20	0.06	1.03	0.03	0.216	0.000477	0.000003	0.000086	0.000004	0.002896
11	328	232	28	41	0.15	0.42	0.18	0.02	0.002	0.000533	0.000026	0.000163	0.000001	0.002661

In Table 8, a few parameter from each parameters group (see Table 2 to 7) is tentatively selected from a small part of the conditionally formatted database. In Table 8, the greenish colour indicates concentrations less or equal to the natural background, the yellow colour indicates concentrations between the natural and the

Standard, and the reddish colour indicates concentrations equal or greater than the Standard.

As can be seen from Table 8, it has been possible to organize data in a meaningful way, from which the general groundwater quality situation can be observed quickly. The whole database formatted in this manner has portrayed the overall groundwater quality situation, and this can be considered as an initial stage from which planners and decision makers could have some common understanding on what the database could tell. However, as explained in the next section, a better understanding of the situation can be attained by relating those concentration ranges with spatial locations.

5. Spatial presentation of the concentration ranges of selected few parameters

So far, the analytical database was viewed only in relation to the concentrations of the parameters and the respective Standards. Since the analytical database is also tied to well and aquifer parameters, it becomes equally important to oversee spatial relations (**Fig. 2**).

For the sake of illustrating the methodology discussed in section 3, variable concentration ranges of TDS and nitrate are spatially presented (figure 2 - upper maps). Also, for the sake of illustrating the methodology discussed in section 4, concentration ranges of antimony and selenium are spatially presented (figure 2 - lower maps).

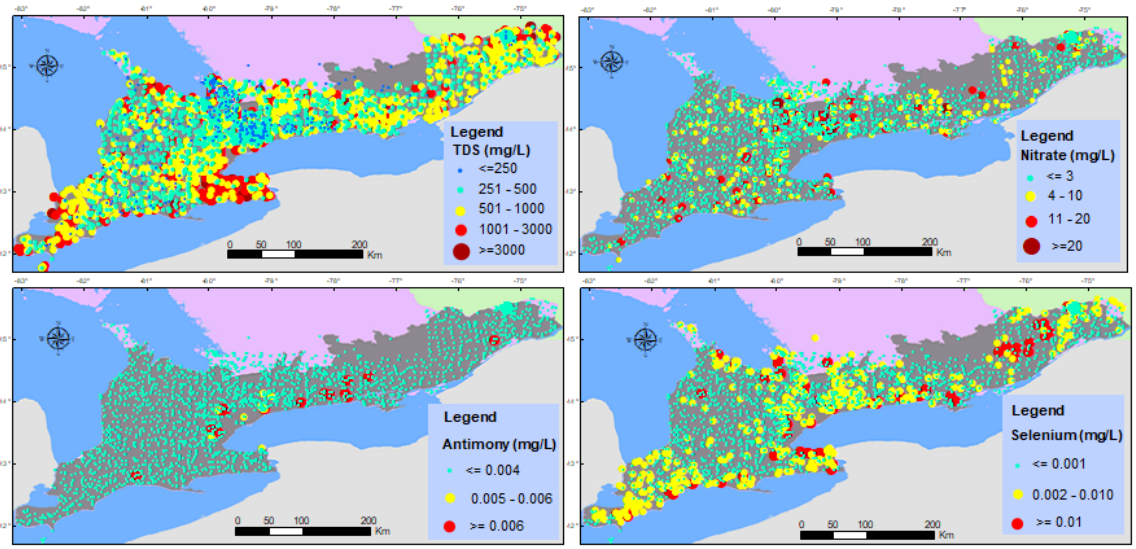

Figure 1: Examples of spatial groundwater quality visualization based on meaningful concentration ranges from tables 2, 4 & 6 that are plotted on the Southern Ontario maps

For the sake of illustrating the methodology discussed in section 3, variable concentration ranges of TDS and nitrate are spatially presented (figure 2 - lower maps). Also, for the sake of illustrating the methodology discussed in section 4, concentration ranges of antimony and selenium are spatially presented (figure 2 - lower maps).

It can be surmised that optimum information can be obtained from the database and the respective GIS mapping when meaningful concentration ranges are selected in the manner described in the previous sections and mapped accordingly.

6. Conclusions

All the methodology employed in this study is found to be very useful in facilitating an initial interpretation of huge water quality databases.

The study has revealed spatial water quality variations both on maps and on the database that depict specific parameter concentration ranges that may imply specific human health and environmental conditions. Of particular interest in making use of concentration ranges mentioned in this study, while mapping on GIS, are total dissolved solids (TDS), hardness, Langelier Index (LI), pH, fluoride, nitrate and sodium. For the rest of the parameters, this study has made use of the natural background values and existing Standards.

Among the trace metals, iron, manganese, antimony, aluminum, cadmium, selenium, silver and molybdenum, are found to be relatively more significant in the groundwater quality of Southern Ontario than the rest of the trace metals.

A number of trace metals, such as mercury and chromium had their concentrations below the MDL (less than 2% of the total samples are detected in both cases). This may not mean that they are absent from the samples, but the detection capability of the apparatus in which they are measured may not have been precise enough for the detection of the respective trace metals.

It is quite often desired to know, for economic reasons or otherwise, which parameters are actually the most significant within a given area. This study has attempted to categorize the parameters according to their levels of significances in Southern Ontario. But, it should be clear that omitting any parameter from the list for chemical analysis means losing the respective information that that parameter provides.

In general, the methodology discussed in this study is very helpful, especially in highlighting possible hot spot areas (areas where groundwater quality has deteriorated, either due to natural conditions or anthropogenic effects). However, what we see on such maps do not always reflect unchanging situations, since significant concentration variations could occur when such a database is used as in the study representing data from multiple years and different months when groundwater levels are high or low depending on seasonality. This study is preliminary and regional in nature, focused on demonstrating a methodology that quickly provides basic information that can be used as a lead for a more detailed investigation where needed. More work supported by a similar method using other databases needs to be carried in order to assert the information provided.

Acknowledgements

The writer acknowledges all organizations and agencies that have provided data to the program, including the Ministry of the Environment and Climate Change (MOECC), Environmental Monitoring and Reporting Branch

(EMRB), and the Ontario Geological Survey (OGS).

The databases used in this study have been constructed and managed by the Oak Ridges Moraine Groundwater Program (ORMGP). The writer acknowledges and is grateful for providing me the access to the program's extensive water quality, aquifer and well database under the guidance and leadership of Mr. Steve Holysh.

References

[1] McNeely, V.P. R.N., Neimanis V.P., and Dawyer L, 1979: Water Quality Sourcebook, A Guide to Water Quality Parameters; Inland Waters Directorate, Water Quality Branch, Ottawa, Canada.

[2] Bowen, H. J. M, 1979: Environmental Chemistry of the Elements; Academic Pres., London. New York, Toronto, San Francisco; A Subsidiary of Harcourt Brace Jovanovich, Publishers.

[3] Haile-Meskale, M. 2007 (unpublished): A Preliminary Groundwater Quality Analysis, An Interpretation of the Analytical Data From the Provincial Groundwater Monitoring Network (PGMN) Wells in Ontario; Ontario Ministry of the Environment, Environmental Monitoring and Reporting Branch.

[4] Haile-Meskale Mezmure, HGSG (2017). An Overview of Saturation State of Groundwater with Respect to Some Common Minerals in South Central Ontario : International Journal of Sciences: Basic and Applied Research (IJSBAR), Vol. 36, No5, pp 32-47.

[5] Haile-Meskale Mezmure and Holysh Steve (2016). Some Aspects of the Origin of the Naturally Occurring Sodium Chloride Waters in Eastern Ontario: International Journal of Sciences: Basic and Applied Research (IJSBAR), Vol. 29, No2 (2016).

[6] Ontario Drinking Water Quality Standards Tables. Appendix D: http://www.sourceprotection-niagara.ca/wp-content/uploads/2014/06/Appendix-D.pdf

[7] US. Department of Health and Human Services. https://toxtutor.nlm.nih.gov/02-006.html.

[8] WHO, 1998: International Programme on Chemical Safety, Environmental Health Criteria 204, Boron; United Nations Environment Programme, International Labour Organisation and World health Organization. http://www.inchem.org/documents/ehc/ehc/ehc204.htm)

[9] WHO, 2004: Guidelines for Drinking-water Quality:

http://www.who.int/water_sanitation_health/dwq/chemicals/en/index.html)

[10] WHO, 2006: Chemical Hazards in Drinking Water: http://www.who.int/water_ls/en/index.html

[11] Zoran Nakić, Kristijan Posavec, and Andrea Bačani, 2007: A Visual Basic Spreadsheet Macro for Geochemical Background Analysis; Groundwater Journal – September – October 2007 (pages 642-647

[12] Haile-Meskale Mezmure, HGSG (2017). https://www.hgsg-water.org/hgsg-exel-programs.